THE APPLICATION OF STRESSCOAT IN THE STUDY OF STRESSES IN THE WEB OF AN INCOMPLETELY DEVELOPED TENSION FIELD BEAM

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Approved:

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TABLE OF CONTENTS

THE APPLICATION OF STRESSCOAT IN THE STUDY OF STRESSES IN THE WEB OF AN INCOMPLETELY DEVELOPED TENSION FIELD BEAM

SUMMARY

Five tests were made with Stresscoat on a diagonal-tension type beam with several panel shapes to determine:

(a) the method of buckling of the web

(b) the location of stress concentrations

(c) the direction of principal stresses in highly stressed regions

(d) the types and relative magnitudes of secondary stresses present

(e) the effect of repeated loadings.

These objectives constituted a qualitative analysis of the stresses existing in the web after buckling. A further aim was to ascertain whether Stresscoat may be adapted in future research to quantitative studies of web stresses.

INTRODUCTION

Considerable emphasis has been placed on the fatigue strength of aircraft and aircraft parts in recent months. These tests, on a beam with an incompletely developed tension field web with Stresscoat, were made in an effort to discover a way of ascertaining what stress concentrations are built up in the web of such a beam after buckling. If such data can be obtained with Stresscoat, it may then be possible to correlate that information with data on cycles of stress reversal per hour in order to provide a clue as to the fatigue life of an aircraft spar. Also, Stresscoat as an experimental tool for checking the theoretical concepts of the way load is carried in a tension field beam was investigated.

In a report prepared by the National Advisory Committee for Aeronautics, Putnam[1] has shown that fatigue strength begins to be of equal importance with ultimate strength in current models of aircraft, where long life and many high speed flying hours are involved.

An aspect of fatigue stressing which renders it more dangerous is its insidious character. The National Advisory Committee for Aeronautics reports that it is so far not practicable to detect fatigue damage to an airplane structure by impact test, or by X-ray inspection[2].

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[1]N. A. C. A. Advanced Restricted Report # L-35, LSF27a, July 1945, "Life Expectancy of Airplane Wings - Normal Cruising Flight," Albert A. Putnam.

[2]Bennett, J. A.: "Effect of Fatigue Stresses Short of Failure on Some Typical Aircraft Metals." Technical Note 983, N. A. C. A., Nov. 1944.

The first indication of fatigue damage occurs in the form of surface cracks which are long and narrow and perpendicular to the direction of maximum tensile stress reversal. These cracks cause dangerous further stress concentrations and considerable reduce impact resistance and ultimate strength. So if they are not discovered immediately upon their appearance, it may be too late.

It is an accepted fact that stress concentrations have a very injurious effect upon fatigue life. Putnam demonstrated that with stress concentration factors of from 2.4 to 6, which are known to exist in conventional aircraft structures, an increase of just 14% in the allowable stress of the material (allowing material to be designed to operate at higher stresses and hence the stress reversal cycle to represent a higher percentage of the true ultimate strength) will reduce the fatigue life of the resultant structure by about 50%. In the last six years, nearly all aircraft structural materials have had increases in Civil Aeronautics Authority allowable stresses.[3] This accounts in part for the increased importance of fatigue failures.

The higher the range of stress covered in a given stress reversal, the more damaging will be that stress cycle to the total fatigue life. Thus, it is obvious that material in which a stress concentration exists will be more highly stressed and will be the earlier causualty to fatigue failure.

The question of course arises as to how we can have a stress

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[3] ''Strength of Aircraft Elements'' ANC-5, Army-Navy-Commerce Committee on Aircraft Requirements U. S. Government Printing Office. Revised 1942, and ammended Oct. 1943. Anonymous

concentration factor of 2.4 or 6, and not have failure of the structure when the airplane reaches the design load of two thirds of the ultimate strength. Plastic deformation relieves the stresses at the concentration points, once the yield point is reached, preventing rupture of the material in a single loading cycle. But those stress concentrations will continue to exist in future cycles of stress. Putnam contends that even after plastic deformation, the stress concentrations continue to exist at full value under cycles of stress reversal. He explains that the effect of the plastic flow is merely to reduce the average stress about which those cycles occur. So they do continue to exist and to wreak their damage on fatigue life, after plastic deformation has occurred.

The data on stress concentration factors in an incompletely developed tension field are extremely meager.

The actual performance of the web itself in a buckled state as it redistributes tensile and compressive stresses to carry the shear load has been the subject of several lengthy and complicated mathematical discussions.[4] Some investigators have used a wide variety of simplifying assumptions while others have kept painfully to the best approximation of the actual conditions.

The results do not agree in many details, but by correlating them with the performance of hundreds of test beams it has been possible to use them to design beams which would bear safely the required ultimate load. The performance is unquestioned, but by exactly what combination

[4]See bibliography, theory of buckled web, references one through eleven.

of primary and secondary tensile and compressive stresses in the web the load is carried is still in considerable question. But, granted that one of these mathematical approaches might be followed to arrive at a stress at any given point, it is a long and tedious process and there are still some assumptions involved in the developed theory which would justify a practical mechanical check of those concentrations, if possible.

When cut-outs, or sloping chord members, or variations in web thickness or stiffener moment of inertia are superimposed upon the problem above, it becomes so complicated that there is no longer a practicable method of calculating stress concentrations.

One of the most promising mechanical tools for determining stress concentrations in the web is the electric strain gage. Due to the secondary bending stresses in the web, however, there are large changes in stress in short distances along or across the buckles. Because of its gage length, the electric strain gage is unfortunately not well adapted to register these changes.[5] Such a gage registers the average stress throughout its gage length. However, around a small cut-out in a web, or across a buckle, the highest stress may be more than 150% of the average stress in the region covered by the strain gage. Further, even where applicable, a veritable myriad of strain gages are required to locate the most stressed points, except when used as a complementary tool to Stresscoat.

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[5]Kuhn, Paul D and Chiarito, Patrick T.: "The Strength of Plane Web Systems in Incomplete Diagonal-Tension." Advanced Restricted Report (not numbered and now not classified), N. A. C. A., Aug. 1942

Another pessibility is photo-elasticity. The photoelastic process has been tried with some success on shear-resistant (unbuckled) beams. In an N. A. C. A. publication[6] Ruffner and Schmidt report the results of a rather thorough investigation of effects of cut-outs on shear-resistant webs. They plotted the stress concentration factor against the ratio of cut-out diameter to beam depth, for several types of cut-outs, to provide valuable information for the builder of shear-resistant beams. However, this method is not applicable when the buckling load is exceeded, so it cannot be used for tension field web studies.

Because it may be applied to the actual structure; because it can obtain results with short gage length; because of the speed and simplicity of testing; and because it presents an overall picture of web stresses, it was considered that Stresscoat might be of considerable help in studying those stresses.

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[6]Ruffner, B. F., and Schmidt, C. L.: ''Stresses at Cut-outs in Shear-Resistant Webs as Determined by the Photo-Elastic Method.'' Technical Note 984, N. A. C. A. Oct. 1945.

APPARATUS

The Test Structure. The beam tested was built up out of 24ST aluminum alloy except for the chord members which were made of two 24ST aluminum alloy angles and a cap strip of mild steel.

The chord members and stiffeners were symmetrically placed about the web, in order to reduce stress concentrations in the web due to stiffener eccentricity, and to make the beam as nearly a simple incomplete tension field structure as possible. Bolts were used in assembly throughout, in order to simplify the task of making changes in stiffener spacing, and to allow for possible changes in web.

Tests 1, 2, and 3 were made with a 3-panel beam. The center panel had a stiffener spacing of 15 inches. (The end panels had stiffener spacings of 6 inches at free end and 5 inches at fixed end for all tests. However, patterns in the end panels were regarded as interesting but inconclusive, because of the uncertain edge conditions.) The wide stiffener spacing gave the chords in the center panel the effect of being quite elastic, allowing considerable bending of the chords and consequent redistribution of diagonal tensile stress at top and bottom center of that panel.

In tests 4 and 5, the center panel was split into a 6 inch and a 9 inch panel, by introduction of a new stiffener. The secondary bending in the chords was thereby reduced, and this case is more typical of the average diagonal-tension field web.

The web was bolted at the fixed end of the beam directly into a heavy angle which was welded to a backing plate heavily bolted to the test jig.[1] The chord members were bolted at the fixed end to heavy angles which were in turn bolted to the same backing plate which supported the web.

The beam was loaded upward at the free end, through a backing plate of steel attached to the end stiffener. Load was applied in tests 1 through 4 with a hydraulic jack, For test 5, when a constant preload was to be maintained for a considerable length of time, a weight-linkage system was used to supply the preload, and the subsequent test loads were added by means of the hydraulic jack.

The Test Apparatus. Stresscoat is the trade name for a group of lacquers put out by the Magnaflux Corporation, which when sprayed upon a surface harden into a uniformly brittle coating.

As load is applied to the structure whose stresses are in question, elastic deformation takes place. The Stresscoat, being a brittle material, begins to crack on those members of the structure in tension. The actual value of strain at which it begins to crack is dependent to a certain extent upon the thickness of the coating, the temperature, and the humidity. (The last two factors are especially critical and results are much improved if temperature and humidity can be closely controlled from the time of spraying through the completion of the test.) Within a range of coating thicknesses from .003 inches to .006 inches the strain at first fracture of the brittle coating is practically constant, so that factor can be eliminated. Further accuracy is obtained

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[1]See figures 1 and 2 for pictures of beam and test set-up.

by spraying several calibration bars at the same time the test structure is being sprayed, with as nearly as possible the same thickness of Stresscoat. (The calibration bar is a simple cantilever which when loaded to any given amount at the free end will develop various strains along its length in direct proportion to the stress and which may be computed from the known applied load. Then, if the first crack appears at a known strain of .0008 incher per inch on the calibration bar, the first crack which appears in a given region on the test structure will represent the same amount of strain.)

In making the test, load is applied to the test structure and to the calibration bar at approximately the same time. The test structure is loaded to whatever percent of design load is desired, and the load released. Cracks which develop in the Stresscoat will remain after release of the load. The pattern of cracks developed is then studied in comparison to those which developed in the calibration bar. Notes as to the existing stresses at that load can then be made directly on the structure.

The process is then repeated, loading to a higher load increment, releasing the load, evaluating, and so on. The reason for release of the load after each additional load increment is that Stresscoat is slightly subject to creep, and if the member remained at high load throughout the time required to evaluate the patterns, results would be distorted. Leaving the structure at load for a short time, however, perhaps three to ten minutes, enables us to get compression patterns upon load release, and thus get more information from each test. The Stresscoat creeps while under load, and upon sudden release of load the compression patterns are formed in the same manner as if they were tension patterns, for tension is created in the coating upon load release. If the load be released very slowly, the coating will creep back to its original state, instead of fracturing.

At the end of any given test, the patterns can be etched with a red dye-etchant for better photographic results. This reduces the Stresscoat sensitivity, however, so that quantitative results must be based upon the pattern formation previous to etching.

By using Stresscoats of different serial numbers it is possible to vary the sensitivity over a limited range, and thus get defined values of strain at each point on the structure at varying values of load.[2]

On a structure in which the stress at any point is directly proportional to the load applied, such as a simple cantilever beam of solid rectangular construction, it is possible, once the strain has been determined at any given load, to extrapolate to find the strain at any other load. Such a method will be obviously inapplicable in the case under consideration, except for possibly limited short range extrapolations, for our main interest is centered upon the redistribution of stresses that occur as load is added beyond the buckling range. Whether or not other methods of application will yield quantitative studies of beam stresses is one of the basic problems attacked in these tests.

The details of the techniques employed in each test are recounted in extracts from test logs.

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[2]For a more complete description of Stresscoat and stresscoat techniques, in general, see "Operating Instructions for Stresscoat." Manual furnished by Magnaflux Corp. to purchasers of equipment.

DISCUSSION

These experiments demonstrated that a single test with Stresscoat, which is a very simple task requiring only a few hours work for the complete test, afforded much information, but left also much to be desired. They further showed that a series of Stresscoat tests can yield a wealth of additional information. However, for such a series to be useful, it must be quite lengthy, and the test work must be quite rigorously carried out. Such a series is therefore worth-while for some projects, not for others.

Although these tests were run as a series, the results are here discussed, first as if they were each separate and unrelated experiments, and then as a test series in order to provide a comparison.

<u>Observations upon a Single Test</u>. Test one, alone, reveals that there is a definite application for Stresscoat in buckled thin sheet structures.

From this single test no quantitative values for the average stress in the web at any point are available at any one value of load. A single test reveals only the magnitude and direction of the surface strain at any point on the sheet at whatever load first causes patterns to form at that point.

If Stresscoat can be further developed (considered extremely doubtful) to the point where the patterns can be matched satisfactorily with calibrated patterns throughout the loading range, then a single test with Stresscoat can be used for a complete stress analysis of the web, giving a graphic picture of stress concentrations and maximum stresses.

An effort was made immediately after each 400 or 800 pound load increment in test one to match the patterns which appeared with those on the calibration strip in order to get a better approximation to the actual load at which those patterns appeared. It was found that such comparisons were not reliable and their use was discontinued in subsequent tests. If greater accuracy is required, it can be obtained by reducing the load increments.

The history of pattern formation in test one and the significance of the patterns which developed in that test will be traced below. For all other tests, this discussion will be confined to those aspects of the test which were different from test one.

The patterns of test one will be discussed in the order of their appearance. Their location will be given in reference to a grid coordinate system which has been inscribed directly onto the photographs of the beam made after test one, (see figures 3 and 4). To differentiate between the two sides of the beam, they will be referred to as "near side" and "far side".

No patterns at all appeared at loads up to and including 1600 pounds applied load. When 2000 pounds load was applied, patterns appeared in all 3 panels on the near (soft) coating and in panels 1 and 2 on the far (brittle) coating side of the web. ''(See Log of Test One)''

In panel 1, (the panel nearest fixed end) the near side pattern first appeared in the middle of the panel, (E-5) along the diagonal-tension line, with the cracks at an angle of about 55 degrees to the chords, indicating the principal stress direction about 35 degrees to the chord members, and a stress intensity of 11,000 psi. at 2000 pounds. On the far side, the center of the panel was clear, but tension cracks at about 55 degrees to 70 degrees to the chords appeared in the lower rearmost corner (I-4) and again just above midpoint of rearmost edge of the structure (D-4 to F-4). These cracks are adjacent to the built-in end of the beam, and the angle to which the web is bolted is heavy enough to approach infinite rigidity, having the effect of a clamped edge for the panel. The stress indicated was 10,000 psi. at 2000 pounds. It is considered that the appearance of these stresses at this low load is probably a consequence of clamping action where the stiffeners and chord members flatten out the buckles which exist in mid-panel.

Upon increase of the load to 2400 pounds, on the near (soft) side there was considerable expansion of the original pattern in the center of the sheet, but no other change. Successive increase up to 4000 pounds load brought an increasing area into the pattern, but no other changes, and the pattern did not extend to the edge of the sheet at any point.

On the standard-coated far side, the 2400 pound load causes expansion and evening out of the patterns along the heavy angle, so that the load is distributed more equally along all the bolts except in the upper corner. It is considered that in this corner (A-4) the gusset action as the web helps put load from chord into stiffener cancels to a large extent the effect of diagonal-tension. Note that in the lower corner, gusset compressive action in the web would be perpendicular to the diagonal-tension load, and would tend to accentuate the patterns due to Poisson's ratio effect.

Also at 2,400 pounds, a large pattern developed along the stiffener. The angle of the tension was about the same as that adjacent to built-in end, but the pattern extended much further out into the web. The indicated stress of 9,070 psi. really first occurred at a load of 2,020 pounds, not so far above the load at which first patterns occurred at the other edge of the panel.

Further increases in loading up to 4000 pounds brought only expansion of the previously formed patterns. (However, load was being slowly released to prevent formation of compression patterns, to the greatest possible extent.)

At 4,000 pounds, however, load was instantaneously released, and compression patterns approximately perpendicular to tension patterns appeared in upper center of the panel, (D-6), on the far side.

It will be noted that on the exact opposite side of this panel there is a diagonal-tension pattern, almost exactly perpendicular to this pattern. This is in a region in which the theory indicates we should have a tension field, and indeed, this panel does show almost completely developed tension. But the secondary bending stresses which add on one side and subtract on the other are big enough to determine whether patterns in the direction of diagonal compression will form.

The panel is buckled into two half waves. Looking at the far side of the panel, it buckles toward the observer along a diagonal line following the tension cracks, and buckles from the observer along a line parallel to and following the compression cracks (D-6). The buckle creates tension in two directions on the outside of the sheet, and compression in two directions on the inner radius of the buckle. Apparently the compression component parallel to the diagonal-tension is adequate to prevent appearance of diagonal-tension cracks at (D-6), while the tension component (due outward buckle) at (E-8) actually accentuates the diagonal-tension stress (or adds to it) creating a larger pattern area. On the other hand, at (D-6) the diagonal compressive stress, plus the Poisson's ratio effect of diagonal-tension, plus stress due to inward curvature of the sheet in the buckle, is adequate to cause sufficient creep of the Stresscoat to give compressive load cracks on that side of the sheet where these factors are additive. Thus there is a complicated combined stress problem, with considerable variation in stress through the thickness of the sheet, as well as at different locations in the panel.

In panel 2 (the middle panel) the picture is similar to that in panel 1. It is noted that the first patterns occurred at the same load as in panel 1 on the near (soft) side, and at an earlier load than in panel 1 on the far side. The first patterns all correspond in direction to the diagonal-tension stress, though some are at mid-panel and others represent stress concentrations due to clamping action of the bolts along the stiffeners and chord members.

It is noted that the outboard lower corner (J-27) and inboard upper corner (B-10) remained clear of patterns on both sides. This again points to the combined effect of gusset action and diagonal-tension loads. (In the corners, the secondary bending effects probably reach a minimum, for there is clamping action from two sides to flatten out the sheet.) Considering the two corners without patterns, in both cases the gusset compression and the diagonal-tension have the same direction, and would tend to cancel out.

In the lower inboard corner and upper outboard corner gusset compression would tend to accentuate the existing compressive loads due to diagonal compression and secondary bending and the Poisson's ratio effect of gusset compression would tend to accentuate the tensile stresses occuring at right angles to that gusset effect. Thus the pattern development in the corners confirms what has been shown by theory and by strain gage tests,[1] that in the corners the clamped sheet builds up high compressive stresses to help put the load into the stiffeners so that the stiffener column load is at a minimum at the ends, but builds up toward the center.

On the far (standard coating) side of panel 2, at 3,200 pounds, occurs the first appearance of tensile cracks at approximately 90 degrees to the diagonal-tension cracks. These cracks follow the length of the buckle, and are parallel to the compression cracks. They are the result of the secondary bending tensile stress across the buckle, and occur in spite of the diagonal compressive stress which still exists in the web at that point. This is indicative of rather high secondary bending stresses. Also, this represents the first appearance of cracks in parallel directions on opposite sides of the sheet and the first opportunity to measure net stresses in one direction on both sides of the same sheet at the same place.

If the compression cracks on the near side of this sheet and the secondary bending parallel to it on the far side had appeared at the

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[1]See bibliography, Theory of Buckled Web, references 7 and 8

same load, it would be possible to compute for that load in one direction the average stress existing in the median plane of the sheet. But, since they occurred at different loads, it is clear that there must be other tests with different sensitivities before any stresses in the median plane can be calculated.

The patterns which occur at low loads are nearly elliptical in shape, whether tension or compression. Those patterns which run from corner to corner form almost a true ellipse, while those which occur on either side of the central corner-to-corner ellipse have their major axes bent in toward the corners. This indicates that the clamping action exerted by the stiffeners and chord members affects the shape of the buckle and hence the amount and direction of secondary bending stresses in the area of the web near them. Those patterns which do not run from corner to corner fail to retain their elliptical shape at the ends and this is also attributed to the effect of local stresses induced in the immediate vicinity of the stiff members where the curved sheet is being forced flat.

In tests two and three, coatings of different sensitivity were used, but the tests were otherwise conducted in a similar fashion to test one. In test two, nothing was developed, considering it as a single test, which was in any way different from test one. In test three, the load was carried on up to 4800 pounds, with a very soft elastic coating. This resulted in appreciable permanent set, but had about the same value as a single test as test one or two. It was hoped, using the very soft coatings, to get two complete sets of patterns from the same coating, by first obtaining a set at high temperature and low sensitivity, and allowing time for creep to heal the cracks, and then cooling for the next test to obtain a higher sensitivity. It was discovered that such a process is not very satisfactory because:

(a) load must be kept very low, for in higher load range, the buckling of the sheet would cause permanent cracks to form in the brittle lacquer in spite of the very soft coating, rendering a second use of the coating impossible

(b) it is harder to obtain satisfactory photographs without etching and it is not possible to use a coating further after etching.

On test three etching under load before photographing the patterns was tried for the first time. The etchant increases the sensitivity, so the new patterns which appear have no quantitative significance. They do, however, reflect the existence and the direction of the principal stresses in areas hitherto not stressed adequately to show patterns. Further, etching under load tends to emphasize the tension cracks. In order to balance out the picture, the compression patterns were re-etched immediately after load release. This technique produced sharply defined patterns which were much better suited to photography than those previously obtained.

Test four was the first test made on the beam after the fifteen inch panel had been split into two panels, one each of six and nine inches width. In this configuration there is less secondary bending in the chord members due to shorter span between stiffeners and more frequent clamping of the sheet which increases the critical buckling load so that the beam will bear a higher load.

The beam was preloaded repeatedly to 5800 pounds, and was allowed to remain at that load for thirty minutes, prior to the first test. This procedure was adopted on the basis of results obtained in comparing test one, two, and three. The reasons for it are detailed in the next section of this discussion.

In test four, the highest percentage of total panel area was covered by patterns. Up to a point, these patterns were no more useful than those developed in previous single tests, but at very high loads it was observed that:

(a) tensile cracks in the direction of diagonal-tension stress appeared covering almost the entire panel, including even the inner (compressive) side of the buckles

(b) these patterns are so much expanded that tensile patterns now appear on both sides of the web at the same location, in the same direction.

In order to make any fair approximations as to the net tensile and compressive stresses in the median plane of the web, it is necessary to know the stresses in two directions on both sides of the sheet at the same value of load. In no single test has this condition been satisfied, nor will it be except possibly at low loads in the shear resistant condition. From the results obtained in test four, where patterns on both sides of the web appear at the same value of load (which can occur in the flat regions between buckles) it is possible to compute a resultant strain in one direction for one load. Since this strain is the result of the net tensile stress in that direction plus the strain due to the compressive stress at right angles to it (due to Poisson's ratio) no very accurate determination of tensile stress can be arrived at.

Test five was made with the beam already loaded to 2000 pounds before application of Stresscoat. It was made for the purpose of extending the range of stresses covered in a series of Stresscoat tests. Since it only reflects the changes in web strains from those which existed at 2000 pounds, it is not significant as a single test. In order to evaluate the strains in any direction from this test it is first necessary to know the value of strains in that direction at 2000 pounds load at the point being considered.

Any one of the single tests affords an interesting comparison of web stresses with those predicted on the basis of various theoretical treatments of the diagonal-tension field beam. Tabulations of predicted average and maximum web stresses at loads of 2400, 4000, and 4800 pounds are shown in tables 2, 3, and 4. It is noted that for the fifteen inch panel (panel 2), at 2400 pounds the predicted average diagonal-tension stress in the web ranges all the way from 7680 psi. to 12000 psi., and the predicted maximum stress ranges from 21300 psi. to 33000 psi. depending upon which theory is followed. At 2400 pounds, some patterns are formed in tests one through four. ~~The tensile stress indicated as existing in one side of the web at a load~~ see sheet of 2400 pounds and at various regions in the web are as follows:

	Test one	Test two	Test three	Test four
Near side	10,300	13,500	19,700	10,500
Far side	9,000	7,600	15,600	9,500

These stresses are in the range between the predicted average and the predicted maximum, but none of them approach the value of maximum stress predicted in accordance with the Wagner theory. (33,300 psi.) However, patterns had already appeared at earlier loads in each case. If the stresses in the web were directly proportional to the load at those points where patterns earlier appeared the web stresses would be as follows:

	Test one	Test two	Test three	Test four
Near side	12,600	15,300	40,000	15,300
Far side	11,100	15,000	31,800	14,000

This constant relationship between the load on the beam and stress in the sheet at any given point does not hold. The actual stresses could be either greater than those indicated above (due to increasing effect of secondary bending in the sheet) or less than the stresses indicated above (if deformation of other parts of the panel has tended to relieve those stresses.

This further illustrates the point that no quantitative results can be obtained in a single test. However, it also shows that there does exist in the web a very wide variation in stresses across the panel, vertically, horizontally, and between the near surface and far surface of the web.

<u>Observations upon a Series of Tests</u>. The only possibility of obtaining quantitative results lies in a series of tests at different sensitivities. If sensitivity can be widely enough varied, values of strain in two mutually perpendicular directions on both sides of the beam throughout the desired range of loads can be obtained.

In these tests, tensile sensitivities used ranged from .00070 to .00194 and compressive sensitivities varied from .00092 to .00164. By using slightly lower temperatures or higher serially numbered coatings it would be possible to increase the sensitivity to perhaps .00050 inches per inch strain in tension. That value might be approached for the compressive sensitivity by increasing the length of time that the beam is left at load before release. (It is creep under load which makes compressive results possible with Stresscoat. Since creep is a function of time, varying the length of time that the beam is under load will change the compressive sensitivity. Results can be evaluated by loading the calibration bar in compression for the same length of time.)

The lowest tensile sensitivity used in these tests was obtained by using the softest Stresscoat available. At this sensitivity, cracks which appeared under load tended to heal upon load release, which meant that test results had to be evaluated under load. Increasing the temperature further to obtain a softer coating was not satisfactory, for room temperatures used were already unpleasantly high.

Test five illustrates a method for obtaining the same effect as a much higher sensitivity. When the strains can be determined in two directions on both sides of the same region of the web at a given load, the stresses existing at that point at that load can be determined. Then, if the beam is preloaded to that load and sprayed with Stresscoat while bearing that load, any cracks which appear upon adding further load will be functions of the additional strains, and hence the additional stresses, imposed by the load added in excess of the preload. So long as the proportional limit of the material has not been passed, it will be possible to superimpose the stresses in order to find the true total stress.

No quantitative significance is attached to test five in this case, for these experiments do not constitute a complete series on which a stress analysis of the web might be based. However it is observed in comparing test five with test four that;

(a) the shape of the patterns is essentially the same

(b) apparently the web is more nearly uniformly stressed along the patterns at high load than at low load, for the first patterns are larger and tend to run for the full length of the buckles.

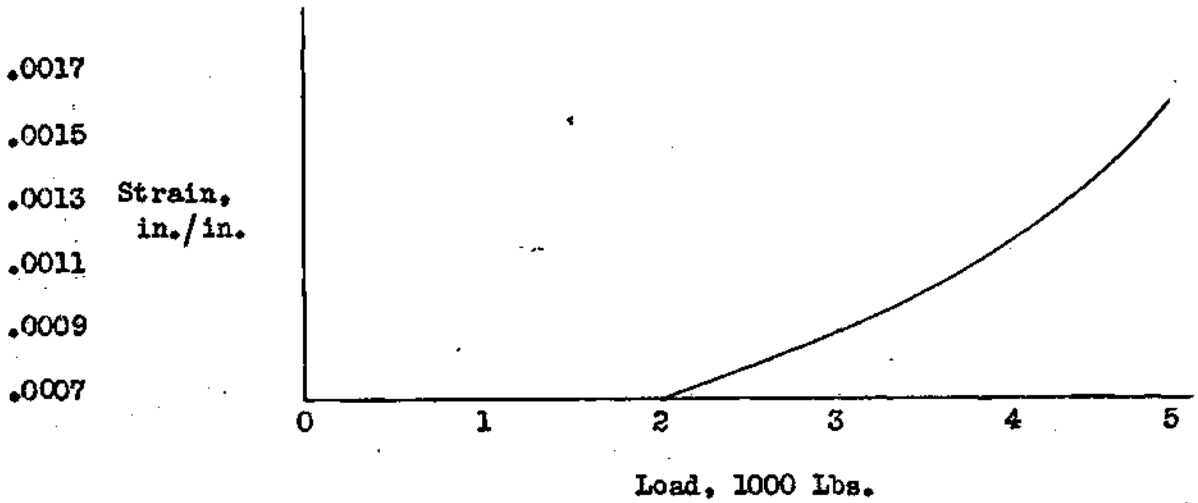
(c) only slight secondary bending tensile patterns appear across the buckles, even at 3600 pounds additional load, so apparently the secondary bending stresses are larger in comparison to the primary stresses at low load than at high load for the same increments of load increase, when the beam has once been deflected enough to acquire permanent set.

Since this series of tests was not designed to give complete stress analysis data, such data will be assumed for one spot in a tension-field web, for one load, in order to illustrate a proposed method of quantitative solution for web stresses by Stresscoat.

Suppose that at the following sensitivities patterns in the diagonal-tension direction appeared at loads as shown, in a series of tests.

Sensitivity	Load
.0007	2,000
.0009	3,000
.0012	4,000
.0016	5,000

Then a curve of strain vs. load may be constructed.



Doing likewise for stresses perpendicular to the diagonal-tension, and doing the same thing for stresses on the opposite side of the sheet, values of strain corresponding to any value of load can be obtained from the curves. Suppose that it is desired to evaluate the stresses at a load of 4500 pounds, and the values of strain taken from the curves for the point in the web whose stress is sought are as follows:

	Side A	Side B
Parallel to diagonal tension	.0014 Ten.	.0006 Ten.
Perpendicular to diagonal tension	.0006 Ten.	.0008 Comp.

Averaging the sides, to obtain strains in the median plane the values are .0010 tensile strain parallel to diagonal tension, and .0001 compressive strain perpendicular to diagonal tension. These strains in aluminum alloy correspond to a tensile stress of 10300 psi. and a compressive strain of 1030 psi.. Solving the two stresses simultaneously to eliminate the effect of Poisson's ratio, it is discovered that the actual strains existing in the web are 11,200 tensile stress, and 2,703 tensile stress, perpendicular to each other.

It is seen, then that the net tensile and compressive stresses in the web can be determined from such a series of tests. However, a prodigious amount of work will be involved, if very many points in the web are to be thus analyzed. A procedure which will considerably reduce the amount of effort involved is to run several tests at widely varying sensitivities to pick out the critical areas, and then for the series of tests, to limit the observations to these areas.

For test one, one side of the beam was sprayed with Stresscoat # 1205, which was the number indicated by the coating selection chart[1] for obtaining a brittle coating of sensitivity between .0007 and .0011. The other side was sprayed with coating # 1203, a softer coating, in order to broaden the results.

In test two, it was sought to check test one and determine the effect of repeated loadings. The beam was loaded repeatedly to maximum load before spraying with Stresscoat. Then it was sprayed, using again a standard brittle coating and a soft coating, and the same loading program as that used in test one was repeated. Because of a difference in temperature between the time of selecting the coating and the time of testing, the sensitivity was different from that in test one, and it was not possible to duplicate the results.

It was observed in test one that the first patterns which appeared represented tensile stresses in the direction of diagonal tension. They occurred at 2000 pounds while the lowest sensitivity was .0009 inches per inch strain. In test two the low sensitivity was .00073 when the first patterns appeared at 1200 pounds load. And the first patterns which

[1] "Operating Instructions for Stresscoat". Manual furnished by Magnaflux Corporation to purchasers of equipment.

appeared were secondary bending patterns, due to the tensile stresses induced across the outer radius of curvature of the buckled sheet. In test one, such stresses were inadequate to form patterns until a load of 3200 pounds was reached. Obviously there had been some yielding of the sheet in the previous loadings which resulted in a slight permanent set in the web. This caused formation of heavy buckles at lower load than in the previous test with a relatively flat sheet. This is in accord with the theory of column action.[2]

In test three, with a sensitivity of .00194, lower than that used in either of the first two tests, the secondary bending stresses again appeared first, and at a load of 1200 pounds. This represents a secondary bending stress of 20,000 psi. at 1200 pounds load, on one side of the sheet. Theoretically, at that load, the web would not even have buckled, and the diagonal tension and diagonal compression would be equal to each other and to the shear stress. But this evidence of the existence of a buckle and quite high secondary bending stresses indicates that after slight permanent set occurs, the beam no longer acts as a shear resistant one up to the critical load, for we already have deformation and, in effect, the action is that of a column with a slightly eccentric load or one whose axis is not perfectly straight but which is elastically supported.[3] This does not indicate a pure tension field web, since diagonal compression is present in increasing amounts as the load increases.

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[2] Hu, P. C.; Lundquist, E. E.; and Batdorf, S. B.: ''Buckling in Compression, Effect of Small Departures from Flatness.'' Technical Note 1124, N. A. C. A., Sept. 1946.

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[3] Timoshenko and MacCullough: ''Elements of Strength of Materials.'' page 262, D. Van Nostrand Co., Inc., Second Edition, 1940.

At 1200 pounds the theoretical diagonal-tension stress is 3000 psi., by Kuhn, Wagner, or early incomplete tension field theory, for this is below the theoretical buckling load. If it is assumed, in accordance with the Wagner theory, that after buckling the diagonal compressive load is zero (a conservative assumption), and assumed further that the critical load equals zero, then the average web stress would be 6,000 psi., in diagonal-tension. Correcting for the flexibility of flanges, the maximum theoretical diagonal-tension stress would be 16,700 psi.. Actually, it is probably less than that, for some diagonal compressive stress does remain. By the most conservative reasoning, then, it has been demonstrated that the secondary bending stress across the buckle is higher than the primary diagonal-tension or diagonal compressive stress <u>in this panel</u> at low loads. This effect is noticeable in the end panels, as well as the center panel, but not to so great an extent, and results in the end panels are inconclusive because of the edge conditions.

At the beginning of tests two and three, there was no visible permanent set in the web. Visual inspection is currently the most widely used method of determining when permanent set occurs in the web of a diagonal-tension beam. The earlier appearance of secondary bending patterns in Stresscoat could better be used to indicate the actual earliest occurrence of permanent set.

This also suggests a preliminary step in Stresscoat testing. Diagonal-tension beams are designed to operate in a stress range such that there will be yielding of the metal on one side of the web. (the outside of the buckles) Therefore, before the first application of Stresscoat, the beam should be repeatedly loaded at least to the maximum load to be covered in that series of Stresscoat tests in order that secondary bending stresses will be the same at any given point at a given load in subsequent testing. The preload should not be sufficient to cause visibly noticeable permanent set. In such a case, plastic flow will probably occur each time the beam is reloaded to that amount, and in no two tests will the same stress exist at a given point for a given load.

Suppose that it is desired to study the fatigue characteristics of a given wing beam, and the Stresscoat pattern at limit load. It has been shown[4] that the maximum loads for which civil aircraft are designed seldom, if at all, occur diring the life of the airplane. From the comments above, and from analyses by the N. A. C. A.[5] it is apparent that the web will have dirrerent stresses at any given load in a stress cycle, dependent upon whether:

(I) the maximum load, or near that, is reached early in the life of the plane

(II) the maximum load is never reached, and the structure is never stressed beyond perhaps sixty per cent of that value.

It is apparent from these Stresscoat experiments that case I would result in higher secondary bending tensile stresses at low loads. However, the same plastic flow which resulted in higher secondary bending stresses for a given low load also acted to relieve primary stresses elsewhere in

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[4]See bibliography, fatigue stresses, references 9 and 10.

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[5]See bibliography, fatigue stresses, references 7, 8, and 11.

the web, so that, without a very thorough investigation of the relative damaging effect of the secondary bending stresses and the primary diagonal-tensile stresses it is not possible to determine which case is critical.

It may be pointed out that when it has been determined which type of loading (case I or case II) under the number of cycles of loading usually encountered[6] has the most damaging effect upon fatigue life, either case I or case II may be simulated in loading the test structure. In making test five of this series, case II was simulated, by initially loading the beam to the highest stress that it was expected the beam would have to carry, before first Stresscoat tests.

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[6]See bibliography, fatigue stresses, references 9 and 10.

CONCLUSIONS

Applicability. The primary significance of this series of tests has been to show that Stresscoat can be made to serve a useful end, both by the airplane builder and the research stress analyst, in the study of any thin sheet stress distribution problems. This investigation was concerned with the application of Stresscoat to diagonal-tension beams, but since that is just a special case of buckled thin sheet theory, an equal amount of information could be obtained from Stresscoat about stressed-skin fuselages or airfoil surfaces. Perhaps therein lies its greatest field of usefulness, for the curved sheet problems are more complex, naturally, than beam problems.

Value of a Single Test. A single test with Stresscoat will show qualitiatively, but not quantitatively:

(a) The location of stress concentration points.

(b) The direction of principal stress throughout the panels.

(c) The way load is put into stiffeners, and clamping effects of stiffeners on buckled web.

(d) The method of buckling, and location of buckles.

(e) The relative importance of secondary bending tensile stresses and diagonal-tension stress at the load at which first cracks appear.

(f) On a group of beams or series of panels, effect of changes in a/b ratio or panel size upon shape and size of buckle, load at which buckles appear, and significance of secondary bending stresses.

(g) Location of regions of low stress, suitable for making cut-outs for inspection or passage of electric, mechanical, or hydraulic parts or fittings.

(h) Proper location and direction of electric strain gages to record principal stresses.

Value of a Series of Tests. By means of a series of tests employing different sensitivities and various artifices such as spraying with Stresscoat under load and changing the length of time the beam remains at load while testing, much more information about web stresses can be obtained. It must be borne in mind that the quantitative accuracy of any single Stresscoat test is only within about fifteen per cent. (This is due to inability to control exactly the thickness of coating, and some slight unreliability of the Stresscoat itself, under perfect conditions.) In any series of tests, these inaccuracies would tend to average out, but the Stresscoat is so highly sensitive to tempature, humidity, and creep that if these factors are not very rigidly controlled, quantitative results will be nil. But within that limit of accuracy it is possible to:

(a) Make a quantitative analysis of web stresses at any point in the web throughout the loading range of the structure, and limited only by the highest sensitivity obtainable. (If maximum sensitivity obtainable is .005 inches per inch, strain, lowest stress in aluminum which can be evaluated is 5150 #/sq. in.)

(b) Determine load at which plastic deformation and permanent set first occur.

Practical Applications. Illustrative of the results which can be obtained from Stresscoat are the observations upon the structure used for these tests:

(a) There is noticeable gusset action in the corners of the web, where the web assists in transmitting axial stiffener loads into the chords.

(b) The permanent set which results in a beam from an initial high loading causes the building up of high secondary bending tensile and compressive stresses at relatively low load.

(c) There is a tendency to build up relatively high stresses at low load adjacent to stiffeners or chord members if there is any unevenness in the amount of clamping action. (Due to poor riveting technique, oversize rivet holes, or other imperfection.)

(d) The angle of principal tensile stresses tends to be approximately the same as the wrinkle angle in the middle of any given panel. However, near the stiffeners or the chord members the greatest tensile stress tends to be almost perpendicular to those heavy members. In a small panel this effect causes rapid changes in direction of maximum tensile stress in short distances.

(e) Several spots can be selected in each panel where a circular cut-out of 1 inch diameter would remove relatively low-stressed material. (Effects of load reversal must be considered here.)

(f) When the load is carried to a very high value, almost the entire panel will show on both sides a diagonal-tension pattern, indicating that the whole web does share in transmitting the load, but that much of it operates at a considerably lower stress than that along the crest of the buckles, where secondary bending parallel to the buckle adds to the diagonal-tension.

(g) In any panel, the buckles tend to run almost corner to corner, but this tendency is considerably more marked in cases where panel width exceeds panel height.

(h) After slight permanent set had occurred, the secondary bending stresses across the buckle actually exceeded the maximum primary stress (diagonal-tension) at low values of load, in the fifteen inch panel.

(i) After slight permanent set had occurred in the fifteen inch panel, it had heavy buckles at very low loads, indicating that it no longer follows the basic assumption in most theoretical treatments of diagonal-tension - it does <u>not</u> act as a shear-resistant beam up to the critical load for, in effect, that load has already been passed when the beam is under no load.

(j) Once permanent set had occurred in the fifteen inch panel, subsequent loadings not in excess of the load which first caused the deformation cause further plastic flow.

It is believed that Stresscoat may prove of considerable assistance to the research stress analyst in the following problems:

(a) To ascertain the effect of plastic flow on one side of the sheet when early permanent set occurs, insofar as the consequent redistribution of stresses is concerned.

(b) To determine accurately and fully the effect upon angle of principal tensile stress, at various points in the panel, of the following: variation in h/d ratio; variation in chord stiffness; variation in panel size; sloping of chord members; cut-outs in the web.

(c) To determine the magnitude and location of stress concentrations existing under the variety of conditions listed above.

(d) To check theoretical computations as to the method of redistribution of stresses to carry shear loads beyond the buckling load.

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BRIEF OF LOG OF TEST ONE

Sling psychrometer reading- 58/75

Coatings selected - Near side - 1203 - soft
Far side - 1205 - standard

Drying time - 24 hours

Sensitivity, uncorrected	Tensile		Compressive	
	Near	Far	Near	Far
Beginning of test	.00095	.00085	-----	-----
End of test	.00090	.00078	-----	-----

RESULTS

Load #	Sensitivity in./in. strain corrected for creep & time	Stress at load, psi.	*Stress at 2000 psi.	
2000	.00102	10500	10500	
2400	.00100	10300	8570	Near
2800	.00104	10700	7690	side
3200	.00100	10300	6430	
4000	.00102	10500	5250	
2000	.00090	9280	9280	
2400	.00088	9100	7600	Far
2800	.00091	9400	7100	side
3200	.00086	8870	5550	
4000	.00088	9100	4500	

SPECIAL CASES INVOLVING MATCHING SENSITIVITIES

Load #	Sensitivity in./in. strain	Stress at load, psi.	*Stress at 2000 psi.	Sensitivity matched
		Near side		
2000	.00108	11100	11100	.00100
2000	.00112	11540	11540	.00104
2000	.00113	11600	11600	.00105
2400	.00111	11400	9300	.00105
		Far side		
2000	.00099	10200	10200	.00092
2000	.00102	10500	10500	.00095
2000	.00108	11100	11100	.00100
2400	.00094	9680	8000	.00090
2400	.00099	10200	8500	.00095
2400	.00105	10800	9000	.00090

Notes: First cracks appeared at 2000 pounds, were in diagonal-tension direction. Compression patterns appeared unexpectedly. Corrected for creep on tensile patterns by leaving beam unloaded between load increments, for a period twice as long as it remains at load during test, and referring to creep correction chart for creep during actual load application. Corrected sensitivity for change in temperature which occurred during test. "Matched sensitivity" technique not satisfactory, abandoned after 2400 pound load. Figures, such as 1000, inscribed inside the pattern contour lines on this test indicate matched sensitivity. The 1000 means patterns match those of .00100 inches per inch strain. Figures on contour lines in this and subsequent tests represent load at formation of pattern. Dashed lines surround compression patterns. Solid lines surround tensile patterns.

* Represents equivalent stress at 2000 pounds load, if straight line relationship between load and stress existed. Figures interesting but not significant.

BRIEF OF LOG OF TEST TWO

No evidence of permanent set from previous test. Preloaded to 4000 pounds twelve times. Intended to determine effect of repeated loadings and check test one.

Sling psychrometer reading - 62/81

Coatings selected - Near side - 1204 - soft
Far side - 1206 - standard

Drying time - 24 hours

Sensitivity, uncorrected	Tensile		Compressive	
	Near	Far	Near	Far
Beginning of test	.00111	.00070	.00159	.00092
End of test	.00121	.00064	----	----

RESULTS

Load #	Sensitivity in./in. Strain corrected for creep & time	Stress at load	*Stress at 2000 psi.	Compressive stress at load
		Near side		
1600	.00124	12800	16000	16400
2000	.00124	12800	12800	16400
2400	.00134	13500	11200	16400
2800	.00124	13500	9100	16400
3200	.00131	13500	8400	16400
4000	.00135	13900	6900	16400
		Far side		
1200	.00073	7520	12500	9480
1600	.00073	7520	9400	9480
2000	.00074	7600	7600	9480
2400	.00074	7600	6350	9480
2800	.00070	7200	5100	9480
3200	.00073	7500	4700	9480
4000	.00073	7500	3700	9480

Notes: Secondary bending stresses in the diagonal compression direction were first to appear. Cracks in the soft coating (near side) tended to heal upon load release. Corrected for by evaluating near-side patterns under load. Sensitivity was far from duplicating test one value. Blame lies in temperature and humidity comtrol.

* Represents equivalent stress at 2000 pounds load, if straight line relationship between load and stress existed; figures interesting but not significant.

BRIEF OF LOG OF TEST THREE

Still no visible evidence of permanent set. Will try softest coatings--no need for psychrometer readings.

Coatings selected - Near side - 1200 - softest
Far side - 1201 - soft

Sensitivity - tensile - uncorrected Near side - .00165
Far side - .00135 (Sealed on Release)

No compressive sensitivity within range of calibration; in 5 minutes load application

RESULTS

Load #	Sensitivity in./in. strain corrected for creep & time	Stress at load	*Stress at 2000 psi.	Compressive stress at load
		Near side		
1200	.00194	20000	33200	——
1600	.00184	18900	23600	——
2000	.00186	19300	19300	——
2400	.00191	19700	16400	——
2800	.00184	18900	13500	——
3200	.00184	18900	11800	——
4000	.00191	19700	10950	——
4800	.00191	19700	8210	——
		Far side		
1200	.00154	15890	26400	——
1600	.00146	15050	18810	——
2000	.00147	15150	15150	——
2400	.00151	15570	12970	——
2800	.00146	15050	10750	——
3200	.00146	15050	9400	——
4000	.00151	15570	8650	——
4800	.00151	15570	6480	——

Notes: First cracks were secondary bending as in test two, in center of center panel, at 1200 pounds load: Compressive patterns which appeared represent stresses in excess of range of calibration equipment. Compressive patterns more permanent in this soft coating than tensile patterns. Etched under load to improve photographic results.

BRIEF OF LOG OF TEST FOUR

First test on four-panel beam. Same web as that used in tests 1, 2, and 3. Slight permanent set to old wrinkles exists after test 3. Preloaded to 5800 pounds 15 times. Old permanent set disappeared. Have very slight buckles remaining in new panels as result of this 5800 pound preload.

Sling psychrometer reading - 60/74

Coatings selected -	Near Side	- 1205 - standard
	Far side	- 1203 - soft

Sensitivity, uncorrected	Tensile		Compressive	
	Near	Far	Near	Far
	.00093	.00086	None in Range	.00167 (based on 5 min.)

RESULTS

Load #	Sensitivity in./in. strain corrected for creep & time	Stress at load	*Stress at 2000 psi.	Compressive stress at load
		Near side		
1600	.00099	10200	12770	——
2000	.00099	10200	10200	——
2400	.00102	10500	8750	——
2800	.00099	10200	7200	——
3200	.00102	10500	6550	——
4000	.00101	10400	5200	——
4800	.00101	10400	4330	——
5600	.00102	10500	3750	——
		Far side		
1600	.00091	9360	11700	17200
2000	.00091	9360	9360	17200
2400	.00092	9480	7900	17200
2800	.00091	9360	6690	17200
3200	.00093	9570	5980	17200
4000	.00092	9480	4740	17200
4800	.00092	9480	3950	17200
5600	.00093	9570	3420	17200

Notes: Near side cracks healing on load release - had to be evaluated under load. Diagonal-tension cracks cover almost the entire web. Heavy secondary bending patterns show at high load.

BRIEF OF LOG OF TEST FIVE

Used weight-linkage system to impose 2000 pound pre-load on beam before spraying. This test designed to accomplish same end as much lowered sensitivity.

Sling Psychrometer reading- 50.5/63

Standard coating is 1200, but will use 1203 and 1205 and raise temperature for test to prevent crazing.

Coatings selected - Near side - 1203
Far side - 1205

Drying time - 24 hours

	Tensile Near	Tensile Far	Compressive Near	Compressive Far
Sensitivity, uncorrected				
Beginning of test	.00102	.00078	.00164	.00143
End of test	.00102	.00078	.00164	.00143

RESULTS

!Load	Sensitivity in./ in. strain corrected for creep & time	Stress at load, psi.	*Stress at 2000 psi.	Compressive stress at load
		Near side		
1200	.00110	11320		16900
1600	.00111	11430		16900
2000	.00111	11430		16900
2800	.00111	11430		16900
3600	.00112	11530		16900
		Far side		
1200	.00083	8550		14720
1600	.00084	8650		14720
2000	.00084	8650		14720
2800	.00084	8650		14720
3600	.00085	8750		14720

<u>Notes</u>: Patterns look much like patterns formed from zero load. All types of patterns appear . Secondary bending tensile patterns are light.

! This is load in addition to the 2000 pounds pre load.
* This column not appropriate when pre load is used.

Table I

PROPERTIES OF BEAM PANELS

Panel No.	2	4	5
Stiffener area, sq. in.	.317	.317	.317
Stiffener Inertia, $in.^4$	.049	.049	.049
Chord Inertia, $in.^4$	.0726	.0726	.0726
Stiffener spacing, (a), in.	15	6	9
Panel height, (b), in.	10	10	10
a/b ratio	1.5	.6	.9
Stiffener bolt spacing, in.	.78	.78	.78
Chord to web bolt spacing, in.	.75	.75	.75
Web thickness, (d), in.	.051	.051	.051
*Area stiff./ad	.529	1.32	.88
*C_2	.36	.90	.63
*Critical shear, per Kuhn, psi. assuming simple support	1070	2860	1550
*Critical shear, per Kuhn, psi. assuming clamped edges	1762	4730	2570

* Refer to, Kuhn, Paul D.: "Investigation of the Incompletely Developed Plane Diagonal-Tension Field." Technical Report # 697, N. A. C. A., 1940.

Table II

COMPARISON OF COMPUTED DIAGONAL-TENSION STRESSES WITH APPARENT EXISTING LOCAL STRESSES AT A LOAD OF 2400 POUNDS

Panel No.		2	4	5
a/b ratio		1.5	.6	.9
Computed tensile stresses	Kuhn, max.	21300	6600	11400
	Kuhn, avg.	7680	6000	7200
	Wagner, max.	33400	6600	19000
	Wagner, avg.	12000	6000	12000
	*Incomplete, max.	26100	6600	13100
	*Incomplete, avg.	9400	6000	8250
Computed compressive stresses	Kuhn,	4330	6000	4800
	Wagner	0	6000	0
	*Incomplete	2600	6000	3750
Near side recorded tensile stress	Test 1	10300	—	—
	Test 2	13500	—	—
	Test 3	19700	—	—
	Test 4	—	10500	10500
Far side recorded tensile stress	Test 1	9070	—	—
	Test 2	7620	—	—
	Test 3	15500	—	—
	Test 4	—	9480	9480
Near side recorded compressive stress	Test 1	—	—	—
	Test 2	16400	—	—
	Test 3	—	—	—
	Test 4	—	—	—
Far side recorded compressive stress	Test 1	—	—	—
	Test 2	9480	—	—
	Test 3	—	—	—
	Test 4	—	—	—

* That theory of the behavior of the incomplete tension field in which it is assumed that the diagonal-compressive stress in the web remains constant after buckling, and equal to its value at buckling.

Table III

COMPARISON OF COMPUTED DIAGONAL-TENSION STRESSES WITH

APPARENT EXISTING LOCAL STRESSES AT A LOAD OF 4000 POUNDS

Panel No.		2	4	5
a/b ratio		1.5	.6	.9
Computed tensile stresses	Kuhn, max.	36700	13100	20600
	Kuhn, avg.	13205	11800	13000
	Wagner, max.	55600	22200	31800
	Wagner, avg.	20000	20000	20000
	*Incomplete, max.	48400	14800	25600
	*Incomplete, avg.	17400	13370	16250
Computed compressive stresses	Kuhn,	5795	8200	7000
	Wagner	0	0	0
	*Incomplete	2600	6636	3750
Near side recorded tensile stress	Test 1	10500	—	—
	Test 2	13900	—	—
	Test 3	19700	—	—
	Test 4	—	10400	10400
Far side recorded tensile stress	Test 1	9070	—	—
	Test 2	7520	—	—
	Test 3	15570	—	—
	Test 4	—	9480	9480
Near side recorded compressive stress	Test 1	—	—	—
	Test 2	16400	—	—
	Test 3	—	—	—
	Test 4	—	—	—
Far side recorded compressive stress	Test 1	—	—	—
	Test 2	9480	—	—
	Test 3	—	—	—
	Test 4	—	—	—

* That theory of the behavior of the incomplete tension field in which it is assumed that the diagonal-compressive stress in the web remains constant after buckling, and equal to its value at buckling.

Table IV

COMPARISON OF COMPUTED DIAGONAL-TENSION STRESSES WITH

APPARENT EXISTING LOCAL STRESSES AT A LOAD OF 4800 POUNDS

Panel No.		2	4	5
a/b ratio		1.5	.6	.9
Computed tensile stresses	Kuhn, max.	48800	16300	25700
	Kuhn, avg.	17550	14625	16205
	Wagner, max.	66800	26700	42400
	Wagner, avg.	24000	24000	24000
	*Incomplete max.	59500	19300	33700
	*Incomplete, avg.	21400	17370	21250
Computed compressive stresses	Kuhn,	6450	9375	7795
	Wagner	0	0	0
	*Incomplete	2600	6630	3750
Near side recorded tensile stress	Test 1	—	—	—
	Test 2	—	—	—
	Test 3	—	—	—
	Test 4	—	10400	10400
Far side recorded tensile stress	Test 1	—	—	—
	Test 2	—	—	—
	Test 3	—	—	—
	Test 4	—	9480	9480
Near side recorded compressive stress	Test 1	—	—	—
	Test 2	—	—	—
	Test 3	—	—	—
	Test 4	—	—	—
Far side recorded compressive stress	Test 1	—	—	—
	Test 2	—	—	—
	Test 3	—	—	—
	Test 4	—	17200	17200

* That theory of the behavior of the incomplete tension field in which it is assumed that the diagonal-compressive stress in the web remains constant after buckling, and equal to its value at buckling.

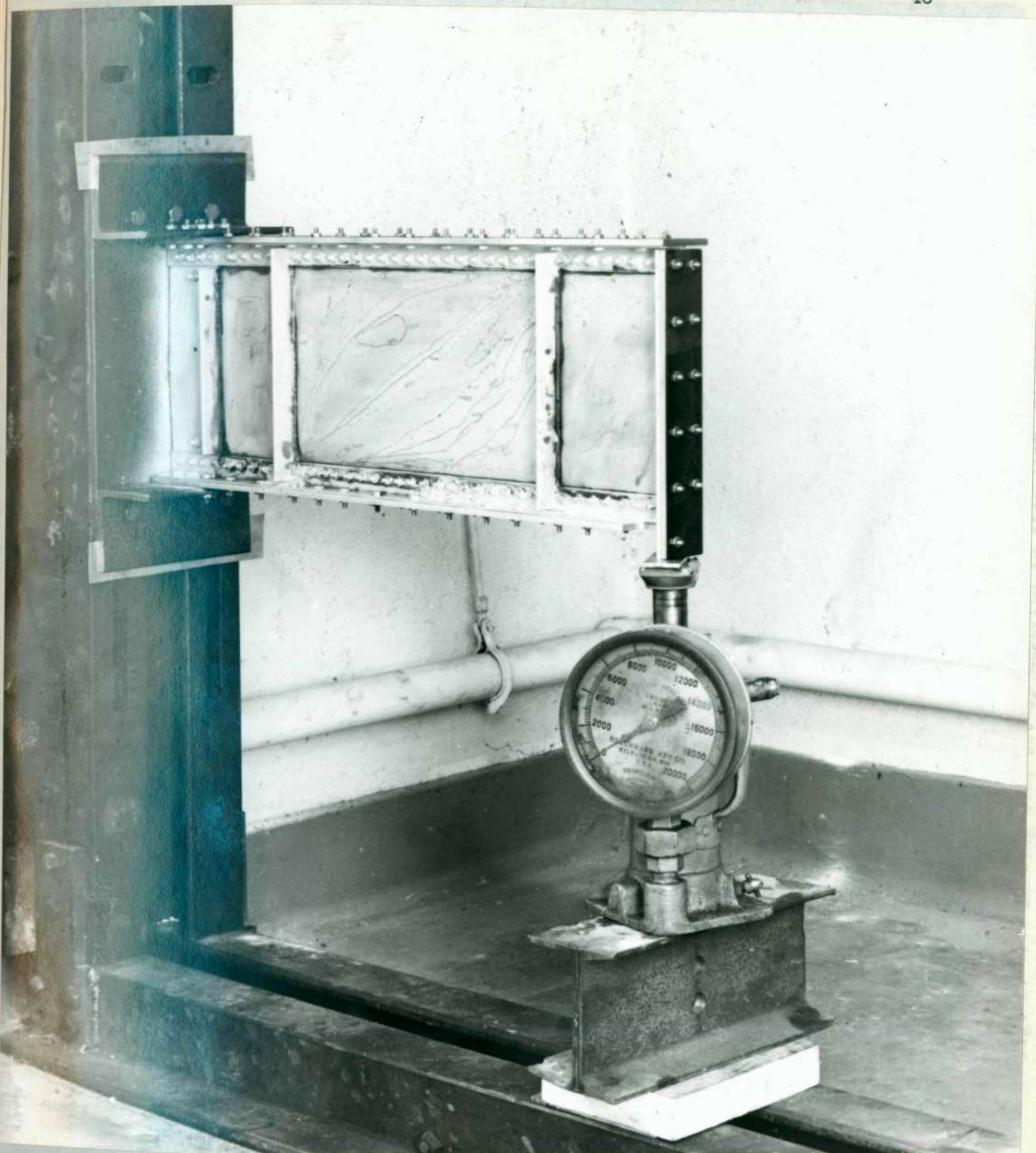

Fig. 1. View showing test set-up employed in tests one through four, with beam of tests one, two, and three mounted in jig.

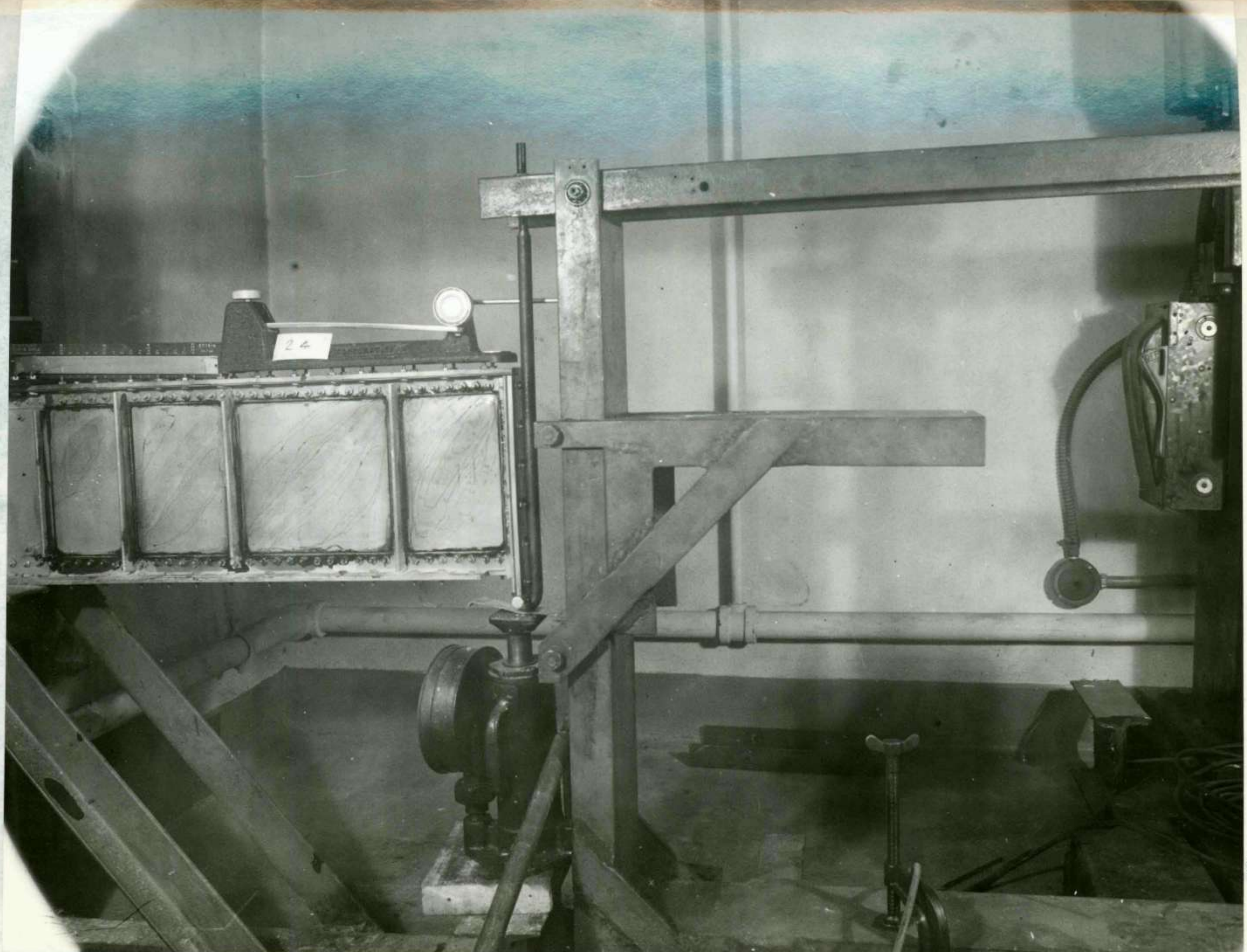

Fig. 2. View showing test set-up employed in test five, with beam of tests four and five mounted in jig.

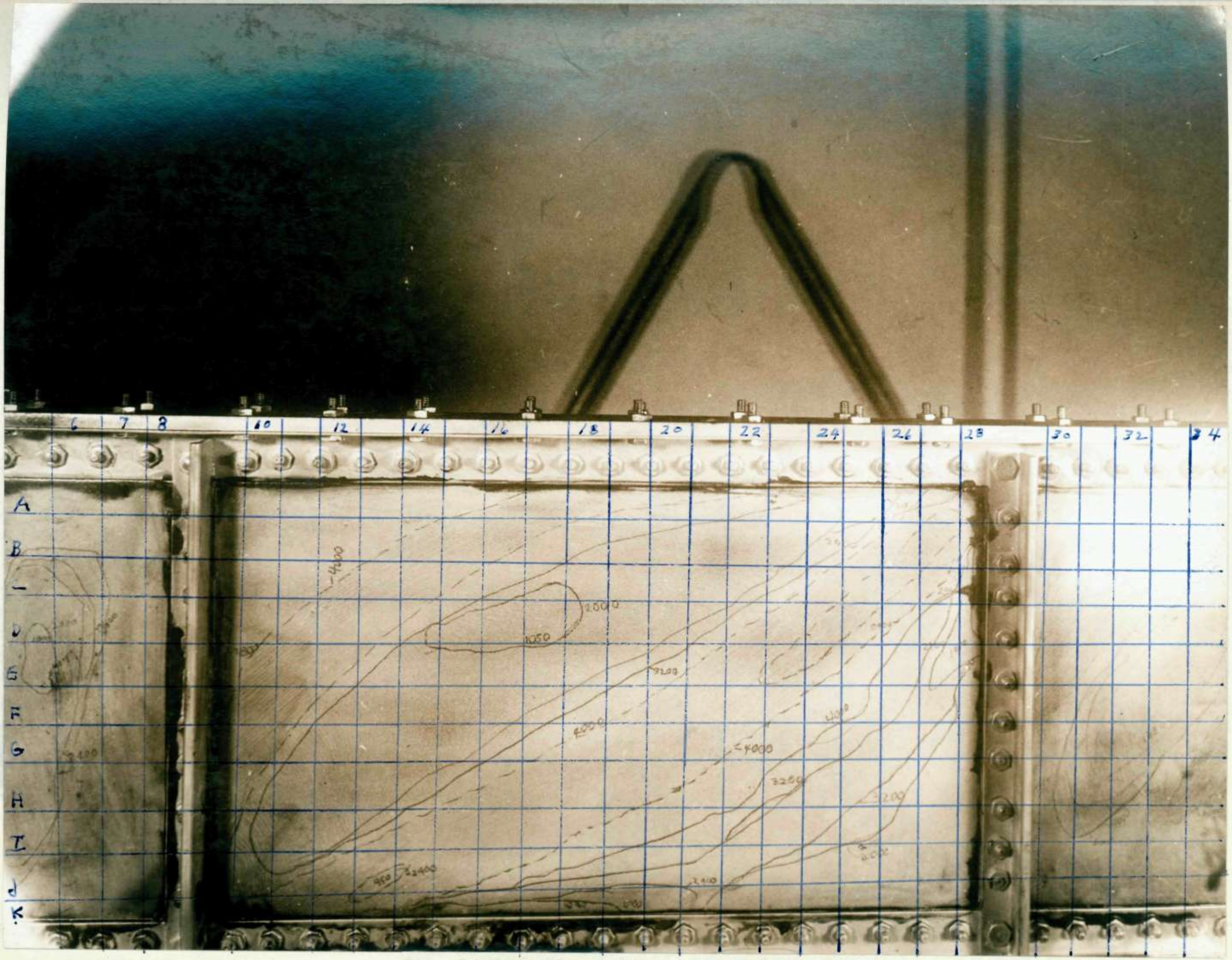

Fig. 3. Near side, test one.

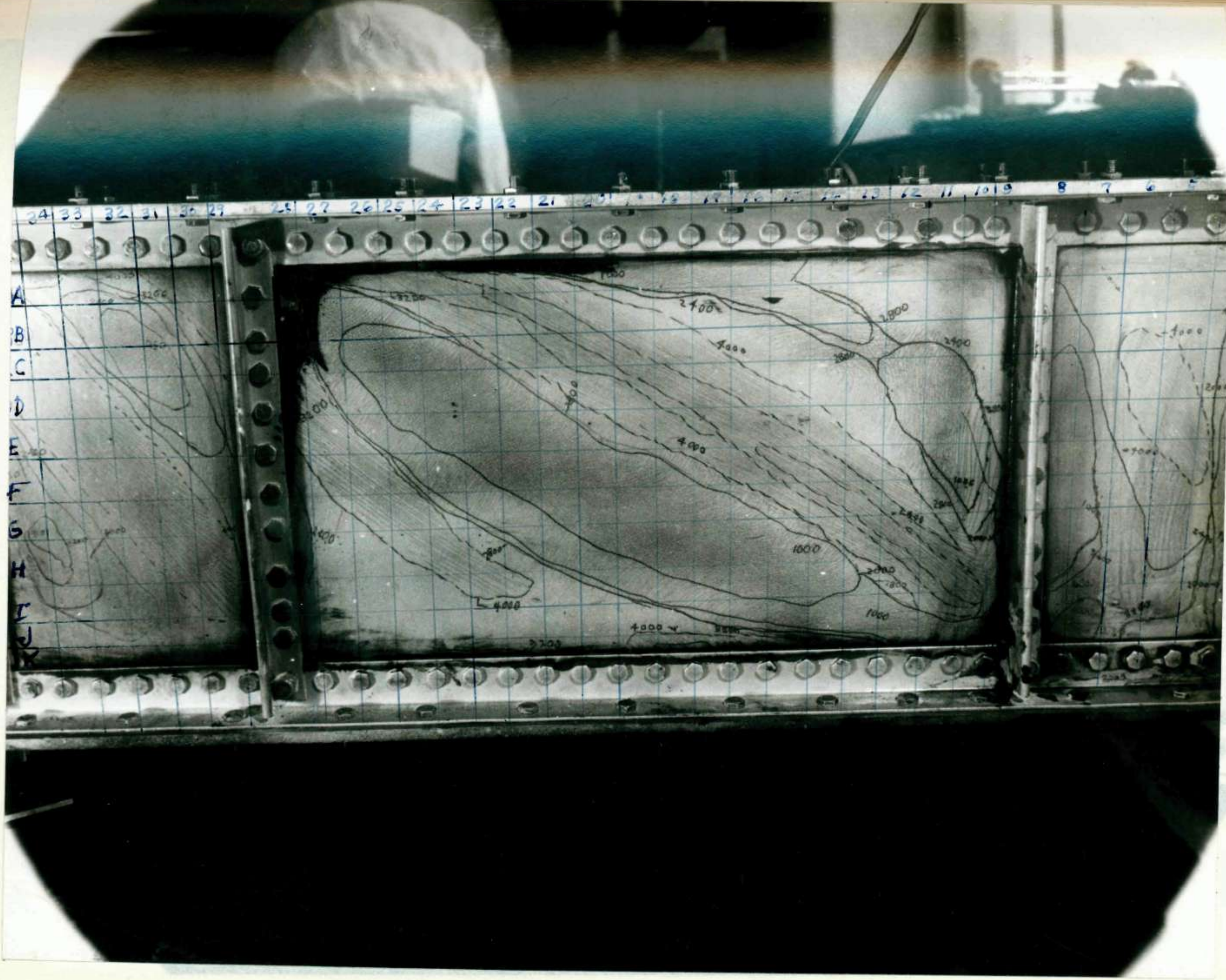

Fig. 4. Far side, test one.

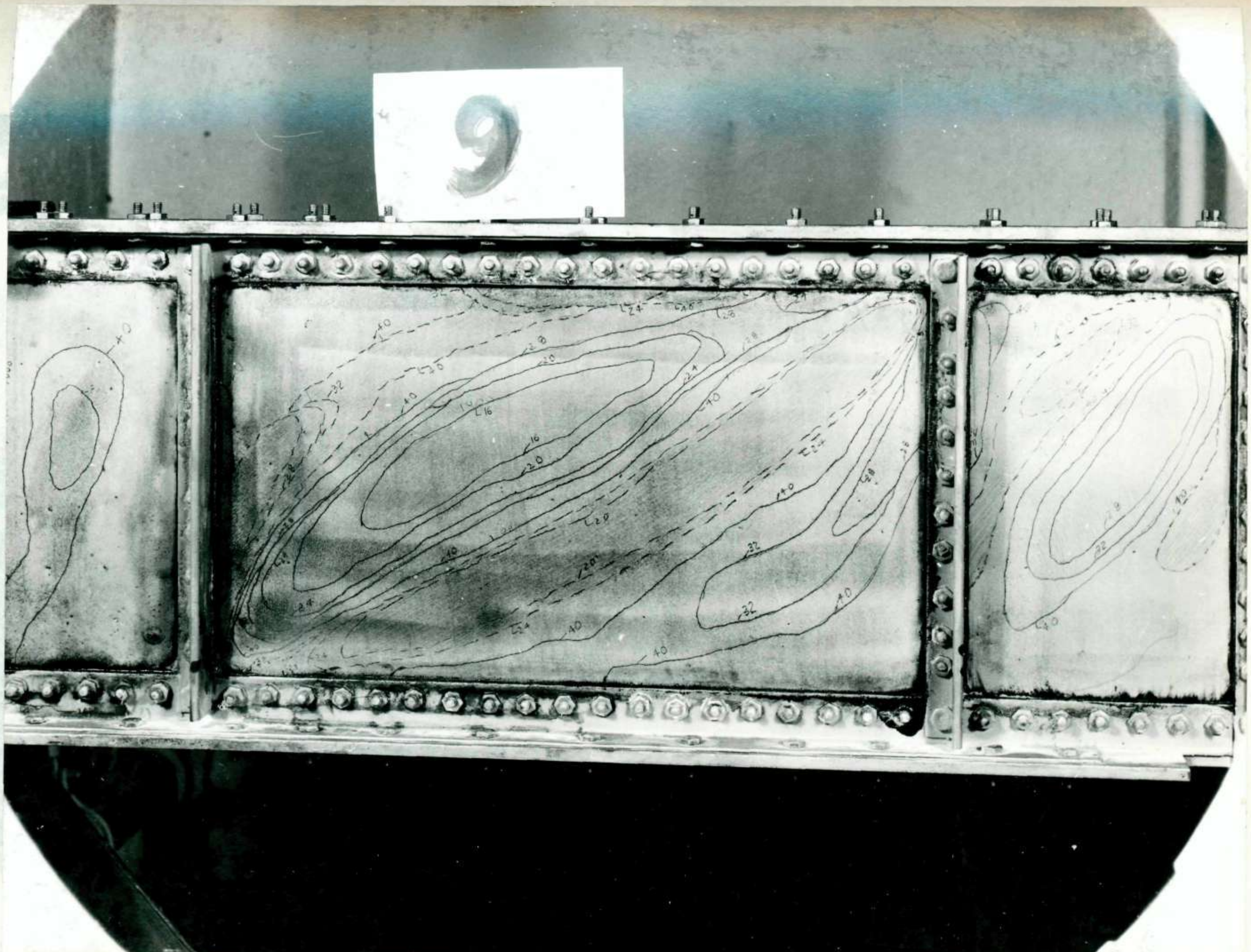

Fig. 5. Near side, test two.

Fig. 6. Near Side, test two.

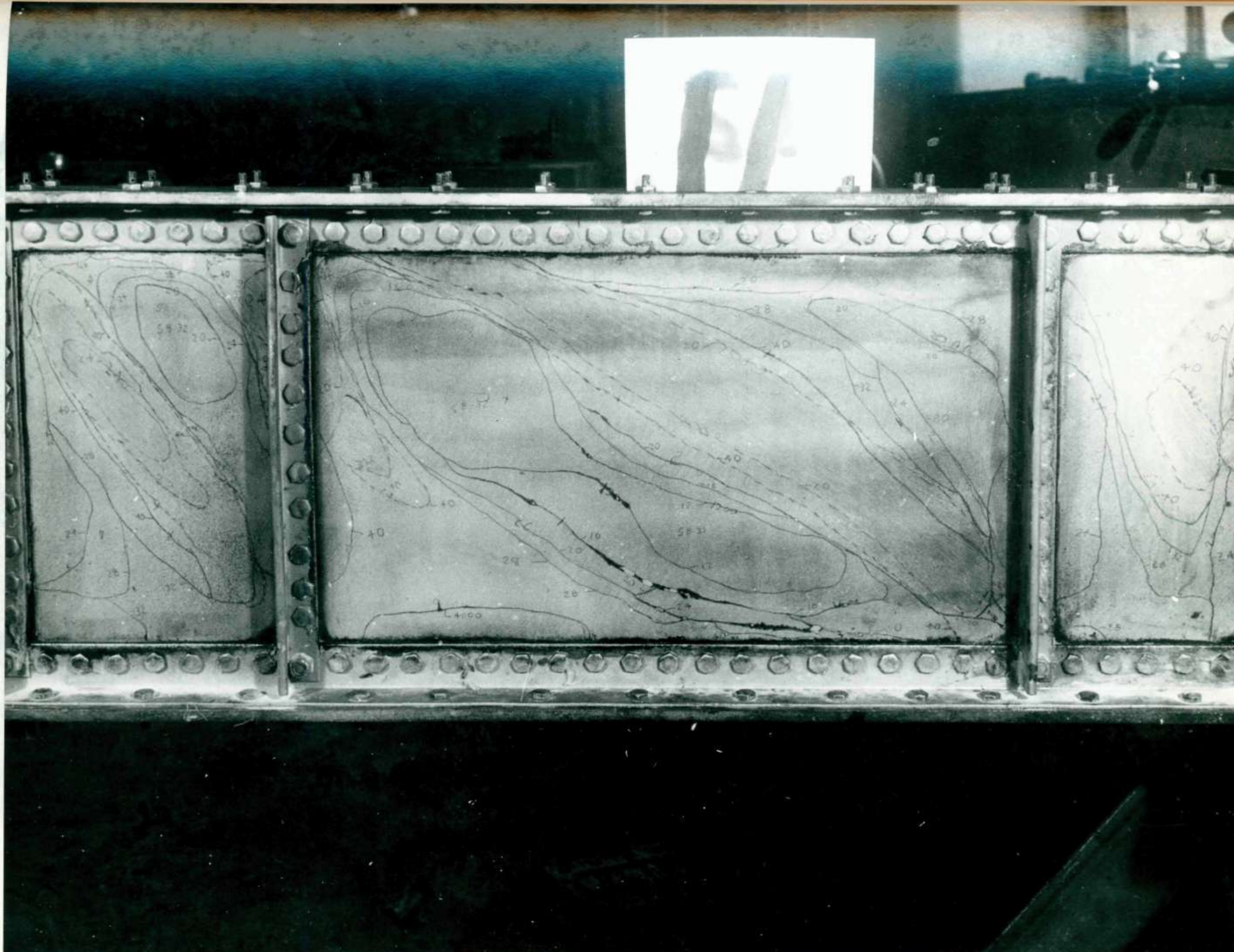

Fig. 7. Far side, test two.

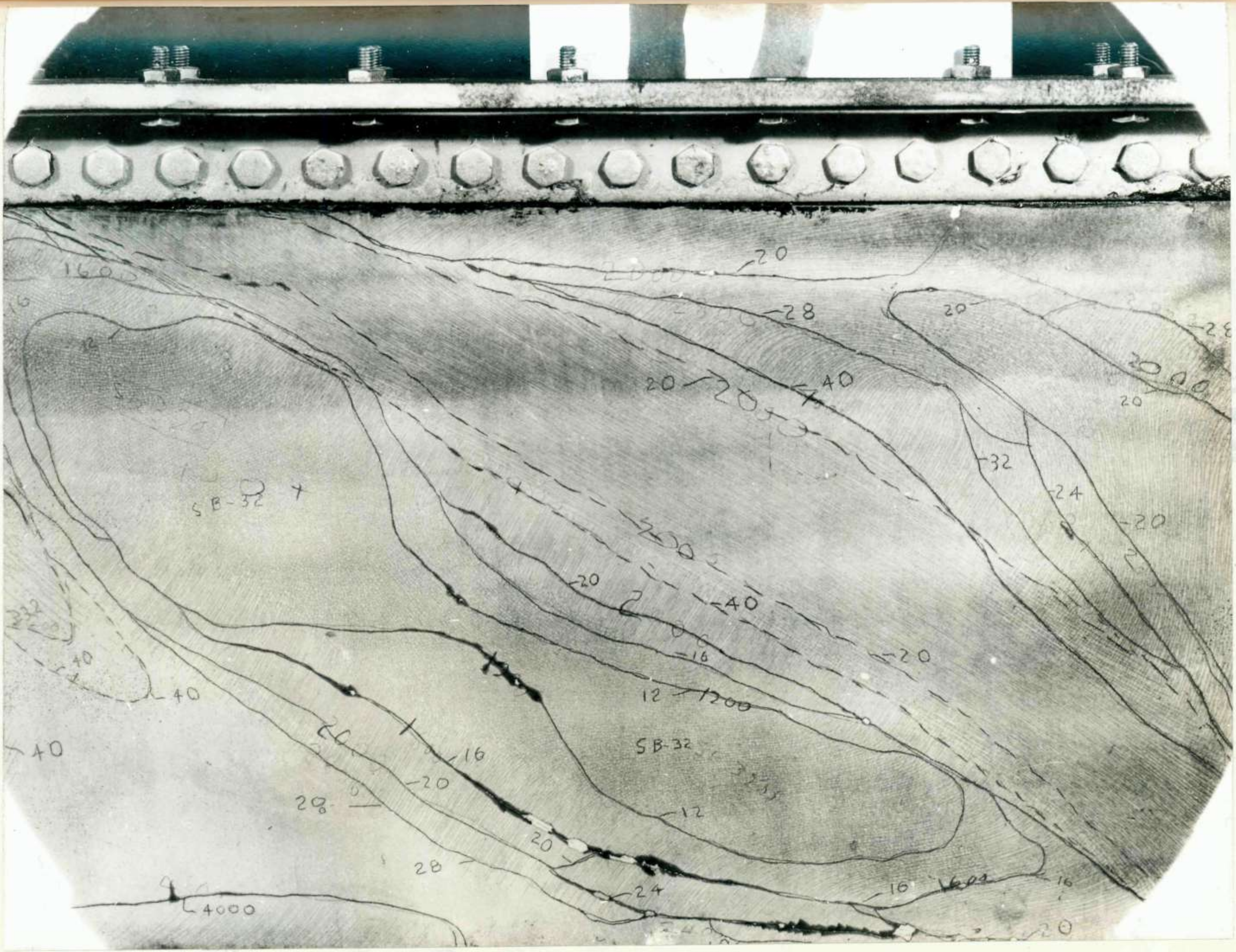

Fig. 8. Far side, test two.

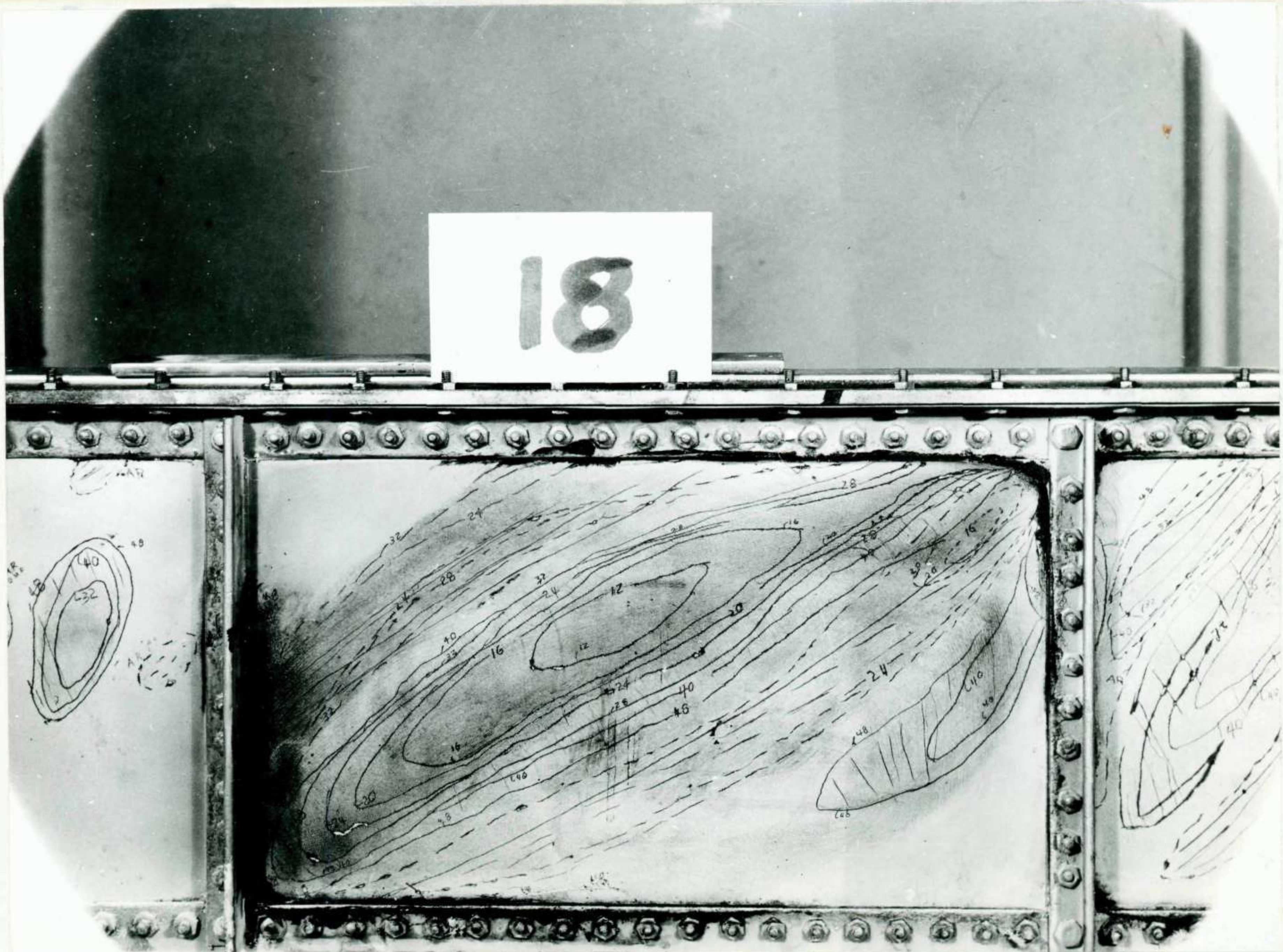

Fig. 9. Near side, test three.

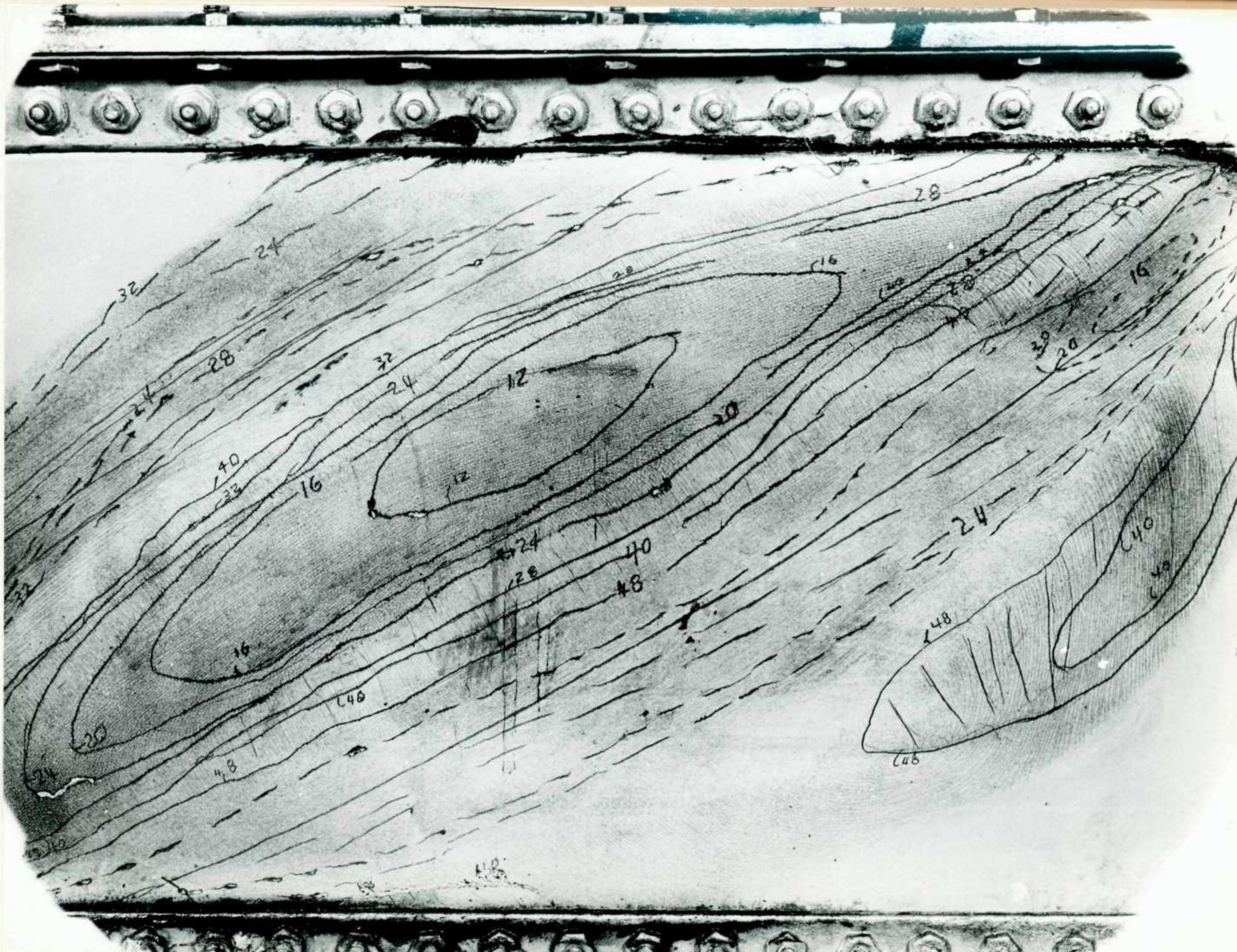

Fig. 10. Near side, test three.

Fig. 11. Far side, test three.

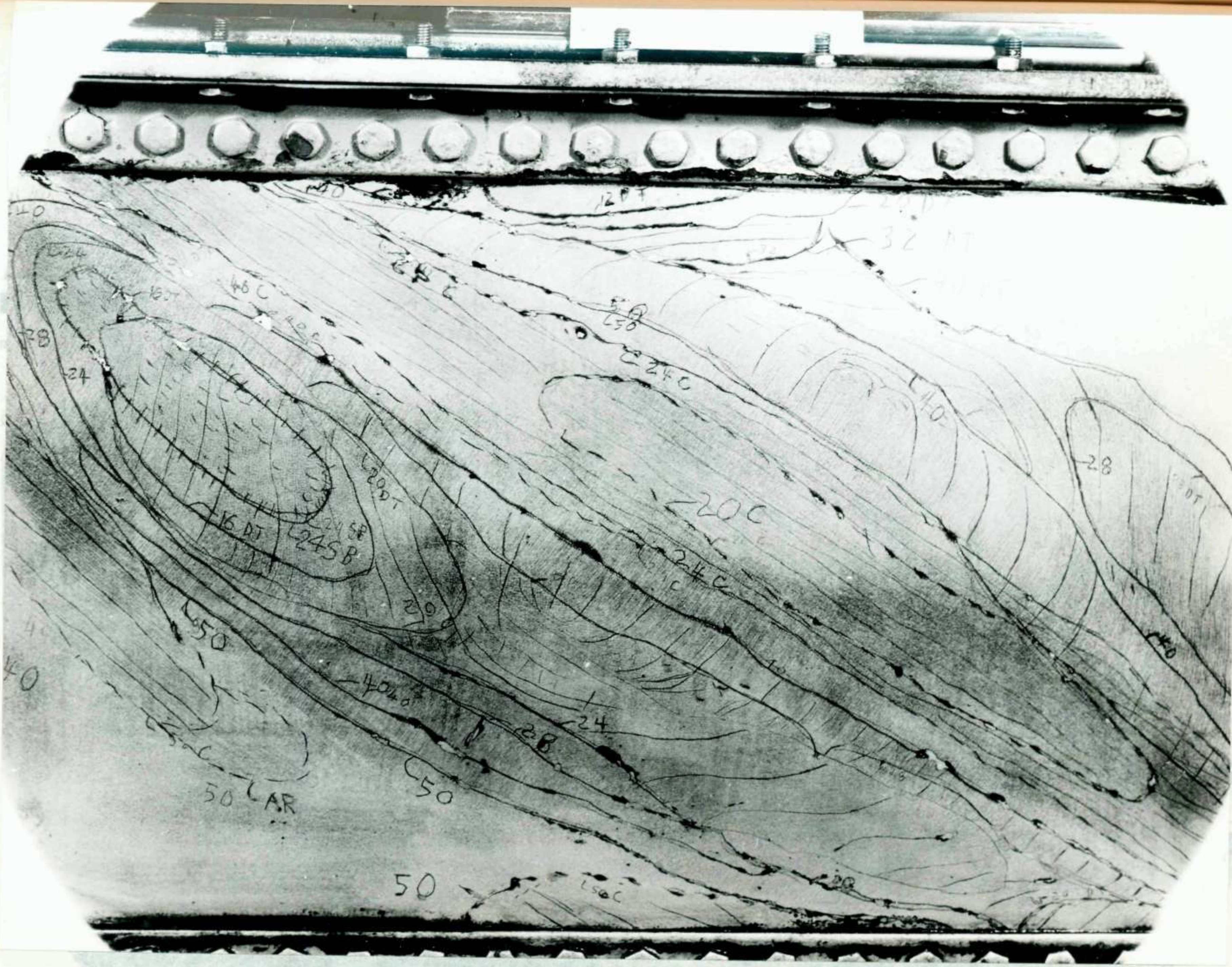

Fig. 12. Far side, test three.

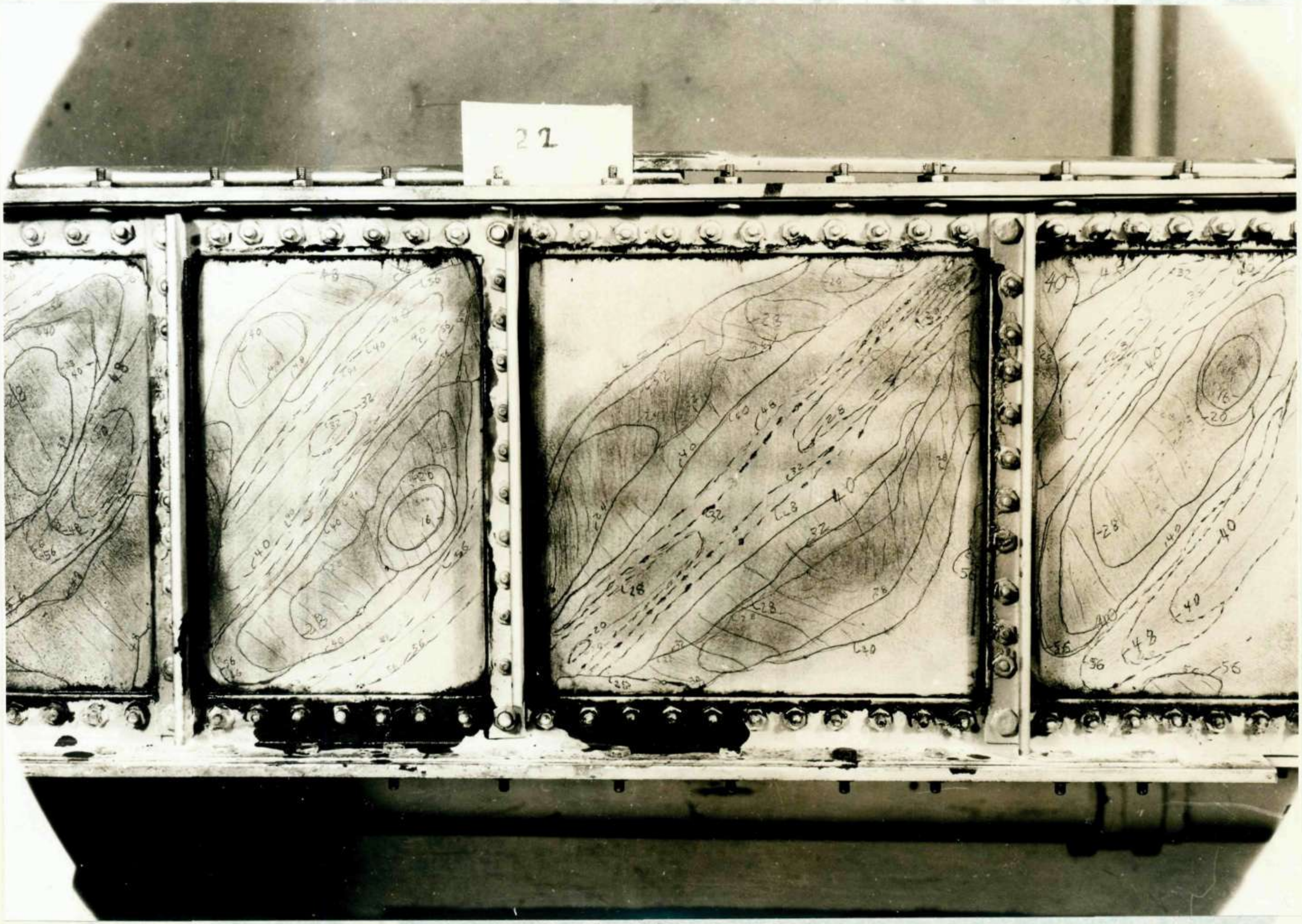

Fig. 13. Near side, test four.

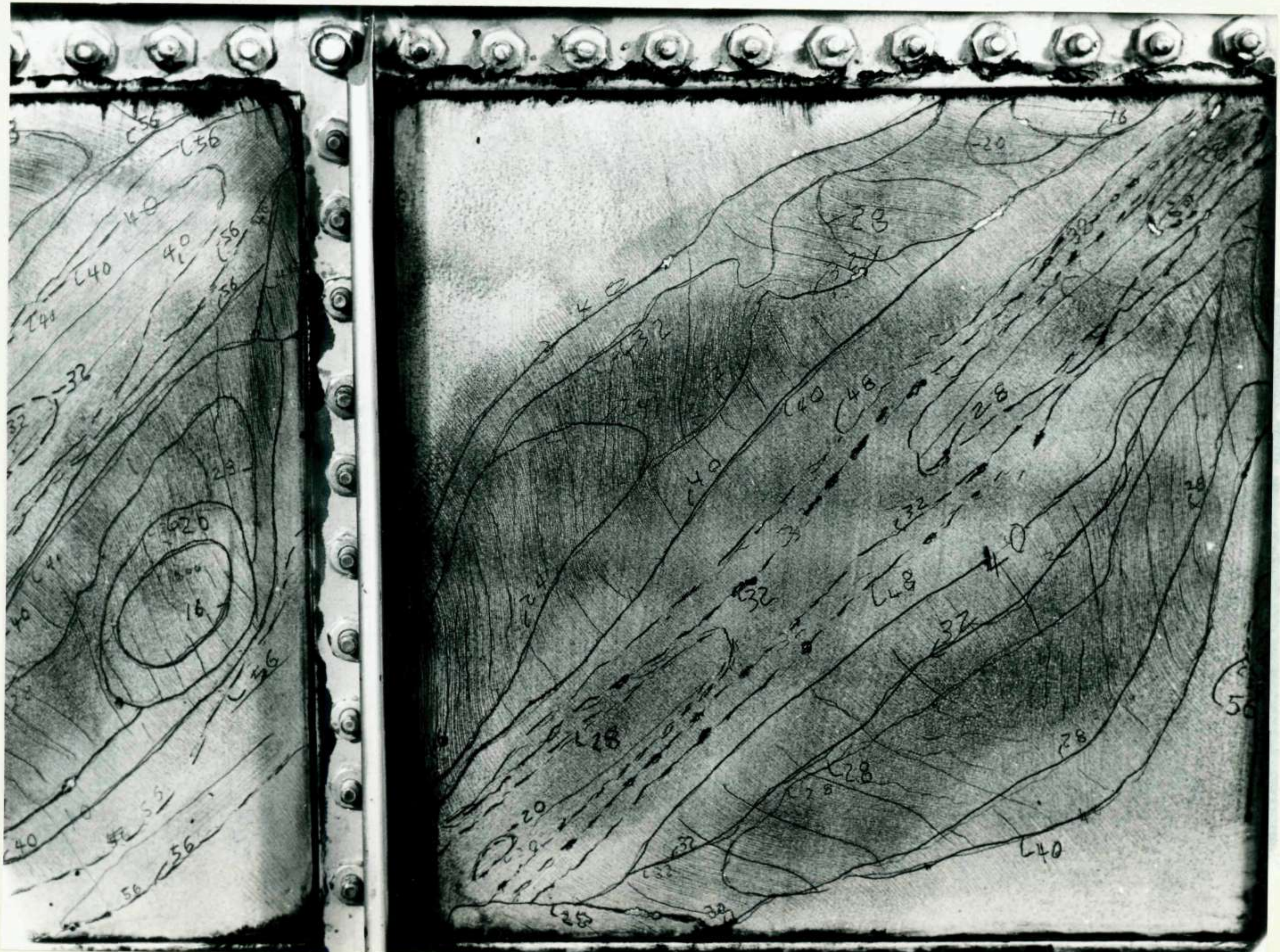

Fig. 14. Near side, test four.

Fig. 15. Far side, test four.

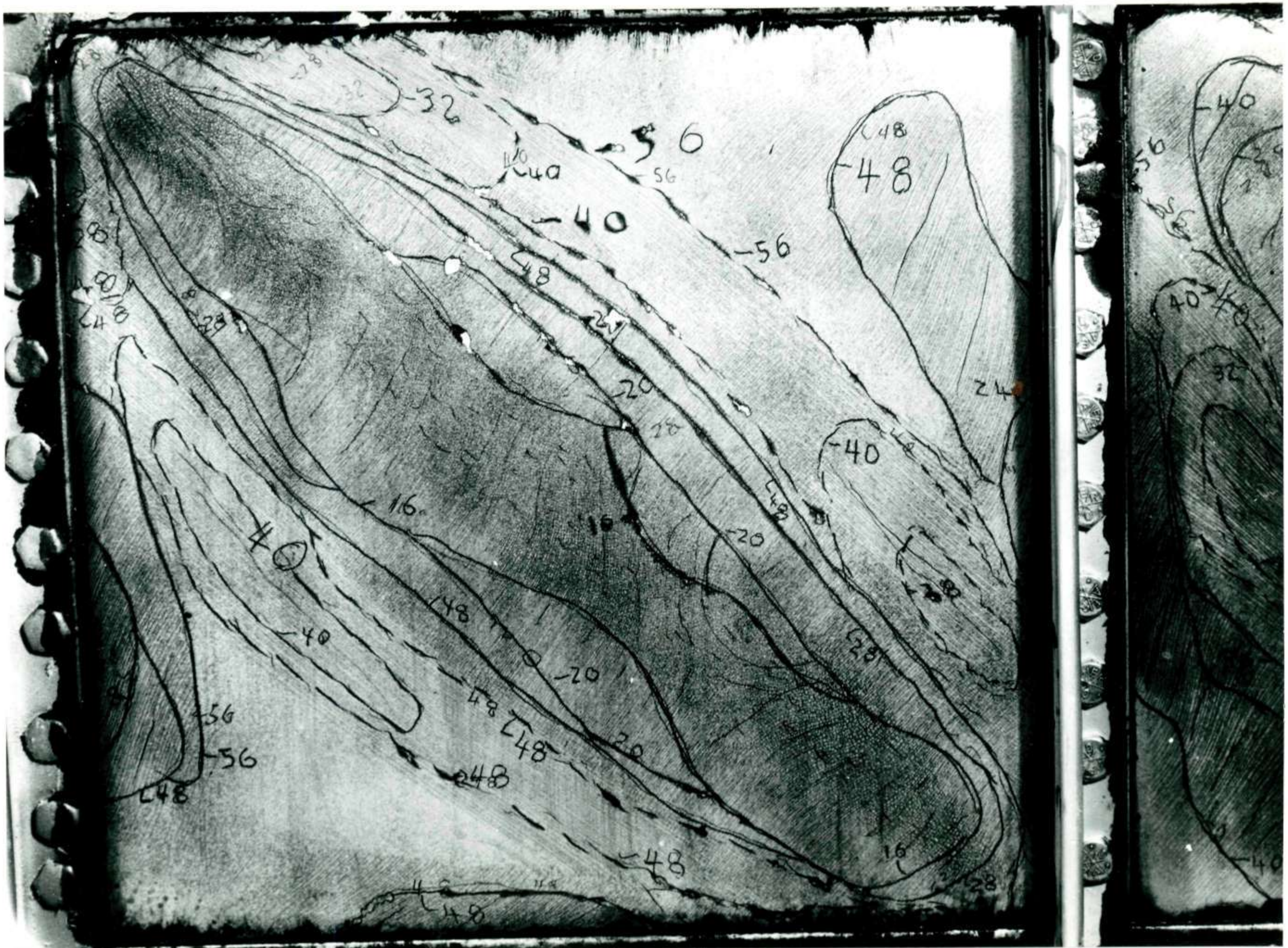

Fig. 16. Far side, test four.

Fig. 17. Near side, test five.

Fig. 18. Near side, test five.

Fig. 19. Far side, test five.

Fig. 20. Far side, test five.